CHARACTERISTICS AND COMPATIBILITY OF THERMOPLASTICS FOR ULTRASONIC ASSEMBLY

WELDABILITY OF THERMOPLASTICS

The principle of ultrasonic assembly involves the use of high-frequency mechanical vibrations transmitted through thermoplastic parts to generate a frictional heat build-up at an interface. This bulletin provides guidelines on the welding characteristics of thermoplastics as well as an understanding of the structure and other factors that affect the weldability of various resins. The term "weldability" is used generically and includes the ability to stake, swage, insert, or spot weld the resin.

POLYMERS: THERMOPLASTIC VERSUS THERMOSET

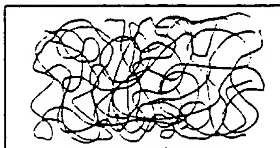
A polymer is a repeating structural unit formed during a process called polymerization. There are two basic polymer families: thermoplastic and thermoset. A **thermoplastic** material, after being formed can, with the reintroduction of heat and pressure, be remelted and reformed, undergoing only a change of state. This characteristic makes thermoplastics suitable for ultrasonic assembly. A **thermoset** is a material that once formed undergoes an irreversible chemical change and cannot be reformed with the reintroduction of heat and pressure; therefore, thermosets cannot be ultrasonically assembled in the traditional sense.

FACTORS THAT AFFECT WELDABILITY

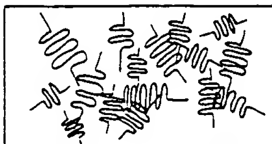
When discussing the weldability of thermoplastics, it must be recognized that there are a number of factors that affect the ultrasonic energy requirements and, therefore, weldability of the various resins. The major factors include polymer structure, melt temperature, melt index (flow), modulus of elasticity (stiffness), and chemical makeup.

POLYMER STRUCTURE

Amorphous resins are characterized by a random molecular arrangement and a broad softening temperature (T_g, glass transition temperature) range that allows the material to soften gradually, melt and flow without prematurely solidifying. These resins generally are very efficient with regard to their ability to transmit ultrasonic vibrations, and can be welded under a wide range of force/amplitude combinations.



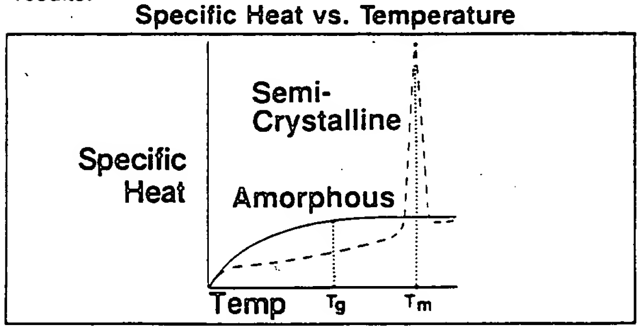
Amorphous Structure



Semi-crystalline Structure

Semi-crystalline resins are characterized by regions of orderly molecular arrangement and sharp melting (T_m, melt temperature) and re-solidification points. The molecules of the resin when in the solid state are spring-like and internally absorb a percentage of the high-frequency mechanical vibrations, thus making it more difficult to transmit the ultrasonic energy to the joint interface. For this reason, high amplitude is usually required. The sharp melting point is the result of a very high energy requirement (high heat of fusion) necessary to break down the semi-crystalline structure to allow material flow. Once the molten material leaves the heated area, these resins solidify rapidly with only a small reduction in temperature. These characteristics therefore warrant special consideration (i.e., higher amplitude, careful attention to joint design, horn contact, and fixturing) to obtain successful results.

Specific Heat vs. Temperature



MELT TEMPERATURE

The higher the melt temperature of a resin, the more ultrasonic energy required for welding.

STIFFNESS (MODULUS OF ELASTICITY)

The stiffness of the resin to be welded can influence its ability to transmit the ultrasonic energy to the joint interface. Generally the stiffer a material the better its transmission capability.

BRANSON
41 EAGLE ROAD, DANBURY, CONNECTICUT 06813-1961 (203) 796-0400

WELDING DISSIMILAR RESINS

A **similar melt temperature** between the materials to be welded is a basic requirement for successful welding of rigid parts, because a temperature difference of 40°F (22°C) can be sufficient enough to hinder weldability (even for a like resin). The lower melt temperature material melts and flows preventing generation of sufficient heat to melt the higher melt temperature material. For example, with an energy director on a part composed of high-temperature acrylic opposing a parallel surface composed of a low-temperature acrylic, the weld surface of the high-temperature part will not reach the necessary temperature to melt. The opposing surface will be in a molten state before the energy director begins to soften, and if the energy director fails to melt, bond strength will be impossible to predict.

In addition, to weld dissimilar plastics, the plastics to be welded must possess a **like molecular structure** (i.e., be chemically compatible) with some component of the material, usually a blend. Close examination of compatible thermoplastics reveals that like radicals are present, and the percentage of the like chemical radical will determine the molecular compatibility and bond strength. Note: Compatibility exists only among amorphous resins or blends containing amorphous resins.

OTHER VARIABLES THAT INFLUENCE WELDABILITY

MOISTURE

Some materials are hygroscopic; that is, they absorb moisture which can seriously affect weld quality.

Nylon (and to a much lesser degree polyester, polycarbonate, and polysulfone) is the material most troubled by this characteristic.

If hygroscopic parts are allowed to absorb moisture, when welded the water will evaporate at 212°F (100°C), with the trapped gas creating porosity (foamy condition) and often degrading the resin at the joint interface. This results in difficulty in obtaining a hermetic seal, poor cosmetic appearance (frostiness), degradation, and reduced weld strength. For these reasons, if possible it is suggested that nylon parts be welded directly from the molding machine to insure repeatable results. If welding can't be done immediately, parts should be kept dry-as-molded by sealing them in polyethylene bags or other suitable means directly after molding. Drying of the parts prior to welding can be done in special ovens; however, care must be taken to avoid material degradation.

FLOW RATES

Flow rate is the rate at which a material flows when it becomes molten. Different grades of the same material may have different flow rates. Such differences may result in the

TABLE 1. CHARACTERISTICS

The codes in this table indicate **relative ease of welding** for the more common thermoplastics. In addition to the material factors covered in the preceding sections, ease of welding is a function of joint design, part geometry, energy requirements, amplitude, and fixturing. **Note:** The ratings below **do not relate to the strength of the weld obtainable.**

Use these tables as a *guide* only, since variations in resins may produce slightly different results.

Material	Ease of Welding		Swaging and Staking	Insertion	Spot Welding	Vibration Welding
	Near Field*	Far Field*				
Amorphous Resins						
ABS	E	G	E	E	E	E
ABS/polycarbonate alloy	E-G	G	G	E-G	G	E
Acrylic[a]	G	G-F	F	G	G	E
Acrylic multipolymer	G	F	G	G	G	E
Butadiene-styrene	G	F	G	G	G	G
Phenylene-oxide based resins	G	G	G-E	E	G	E-F
Polyamide-imide	G	F				G
Polyarylate	G	F				
Polycarbonate[b]	G	G	G-F	G	G	E
Polyetherimide	G	F				
Polyethersulfone	G	F				
Polystyrene (general purpose)	E	E	F	G-E	F	E
Polystyrene (rubber modified)	G	G-F	E	E	E	E
Polysulfone[b]	G	F	G-F	G	F	E
PVC (rigid)	F-P	P	G	E	G-F	G
SAN-NAS-ASA	E	E	F	G	G-F	E
Xenoy (PBT/polycarbonate alloy)	G	F	F	G	G	E

Material	Ease of Welding		Swaging and Staking	Insertion	Spot Welding	Vibration Welding
	Near Field*	Far Field*				
Semi-Crystalline Resins[c]						
Acetal	G	F	G-F	G	F	E
Cellulosics	F-P	P	G	E	F-P	E
Fluoropolymers	P					F
Ionomer	F	P				
Liquid crystal polymers	F	P	G-F			
Nylon[b]	G	F	G-F	G	F	E
Polyester, thermoplastic						
Polyethylene terephthalate-PET	G-F	P				
Polybutylene terephthalate-PBT		P				
Polyetheretherketone-PEEK	F	P				G
Polyethylene	F-P	P	G-F	G	G	G-F
Polymethylpentene	F	F-P	G-F	E	G	E
Polyphenylene sulfide	G	F	P	G	F	G
Polypropylene	F	P	E	G	E	E

Code: E = Excellent, G = Good, F = Fair, P = Poor

* Near field welding refers to a joint 1/4 in. (6.35 mm) or less from the horn contact surface; far field welding to a joint more than 1/4 in. (6.35 mm) from the horn contact surface.

[a] Cast grades are more difficult to weld due to higher molecular weight.

[b] Moisture will inhibit welds.

[c] Semi-crystalline resins in general require higher amplitudes due to polymer structure and higher energy levels due to higher melt temperatures and heat of fusion.

melting of one component of an assembly and not the other. Thus, a melt or flow is created, but not a bond. Consult the résin specifications to ensure compatibility of rates.

RESIN MODIFIERS

Using additives or processing aids during preparation of a resin compound may result in properties not inherent in the base resin. These additives, which can enhance certain areas of processing, can in some cases create problems in ultrasonic welding.

Mold release agents, often called parting agents, are applied to the surface of the mold cavity to provide a release coating which facilitates removal of the parts. External release agents, such as zinc stearate, aluminum stearate, fluorocarbons and silicones can be transferred to the joint interface and interfere with surface heat generation and fusion, inhibiting welding; silicones are generally the most detrimental. If it is absolutely necessary to use an external release agent, the paintable/printable (non-transferring) grades should be used. These grades prevent the resin from wetting the surface of the mold, with no transfer to the molded part itself, thus permitting painting and silk-screening and the least amount of interference with ultrasonic assembly. Detrimental release agents can in some cases be removed by using a solvent, such as TF Freon. Internal molded-in release agents, since they are generally uniformly dispersed internally in the resin, usually have minimal effect on the welding process.

Lubricants (internal and external) are materials that enhance the movement of the polymer against itself or against other materials. (Examples include waxes, zinc, stearate, stearic acid, esters.) Lubricants reduce intermolecular friction (melt viscosity) within the polymer or reduce melt flow friction against primary processing equipment surfaces. Since molecular friction is a basis for ultrasonically induced temperature elevation, lubricants can inhibit the ultrasonic assembly process. However, since they are generally dispersed internally, like internal mold release agents their effect is usually minimal.

Plasticizers are high-temperature boiling organic liquids or low-temperature melting solids which are added to resins to impart flexibility. They do this through their ability to reduce the intermolecular attractive forces of the polymer matrix. They can also interfere with a resin's ability to transmit vibratory energy. Attempting to transmit ultrasonic vibrations through a highly plasticized material (such as vinyl) is like transmitting energy through a sponge. Even though plasticizers are considered an internal additive, they do migrate to the surface over time, and the combination of internal as well as surface lubricity make plasticized vinyl all but impossible to weld. FDA-approved plasticizers do not present as much of a problem as metallic plasticizers, but experimentation is recommended.

TABLE 2. COMPATIBILITY OF THERMOPLASTICS

■ – Denotes compatibility
O – Denotes compatibility in some cases (usually blends)

Amorphous Resins	ABS	ABS/polycarbonate alloy (Cycoloy 800)	Acrylic	Acrylic multipolymer	Butadiene-styrene	Phenylene-oxide based resins (Noryl)	Polyamide-imide (Torlon)	Polyarylate	Polycarbonate	Polyetherimide	Polyethersulfone	Polystyrene (general purpose)	Polystyrene (rubber modified)	Polysulfone	PVC (rigid)	SAN-NAS-ASA	**Semi-Crystalline Resins**	Acetal	Cellulosics (CA, CAB, CAP)	Fluoropolymers	Ionomer	Liquid crystal polymers	Nylon	Polybutylene terephthalate-PBT	Polyetheretherketone-PEEK	Polyethylene terephthalate-PET	Polyethylene	Polymethylpentene	Polyphenylene sulfide	Polypropylene
Amorphous Resins																														
ABS	■	■	■	O								O	O		O	O														
ABS/polycarbonate alloy (Cycoloy 800)	■	■	O						■																					
Acrylic	■	O	■	O		O			O							O														
Acrylic multipolymer	O		O	■								O				O														
Butadiene-styrene					■							O																		
Phenylene-oxide based resins (Noryl)			O			■			O			■				O														
Polyamide-imide (Torlon)							■																							
Polyarylate								■																						
Polycarbonate		■	O			O			■	O				O																
Polyetherimide									O	■																				
Polyethersulfone											■																			
Polystyrene (general purpose)	O			O	O	■						■				O														
Polystyrene (rubber modified)	O												■																	
Polysulfone									O					■																
PVC (rigid)	O														■															
SAN-NAS-ASA	O		O	O		O						O				■														
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Polypropylene																														■

Impact modifiers such as rubber can affect the weldability of a material by reducing the amount of thermoplastic available at the joint interface. They can also reduce the resin's ability to transmit ultrasonic vibrations, making it necessary to increase amplitude to generate a melt.

Foaming agents also reduce a resin's ability to transmit energy. Voids in the cellular structure interrupt the energy flow, reducing the amount of energy reaching the joint area, depending on the density.

Flame retardants are added to a resin to inhibit ignition or modify the burning characteristics. They can adversely affect ultrasonic welding characteristics of the resin compound. Flame retardant chemicals are generally inorganic oxides or halogenated organic elements, and for the most part are non-weldable. Typical examples are aluminum, antimony, boron, chlorine, bromine, sulfur, nitrogen and phosphorus. The amount of flame retardant material required to meet certain test requirements may vary from a few percent to 50% or more by weight of the total matrix, thus reducing the amount of available weldable material. This reduction must be compensated for by modifying the joint configuration to increase the amount of weldable material at the joint interface and by increasing ultrasonic energy levels.

Regrind. Scrap formed during the molding process, e.g., sprues, runners, reject parts, can usually be recycled directly back into the process after the material has been reduced to a usable size. Control over the volume and quality of regrind is necessary, as it can adversely affect the welding characteristics of the molded part. In some cases the use of 100% virgin material may be required to obtain the desired results.

Most colorants, either pigments or dyestuffs, do not interfere with ultrasonic assembly; however, occasionally some pigments (white, black) can influence weldability. Titanium dioxide (TiO_2) is the main pigment used in white parts. Titanium dioxide is inorganic, chemically inert, and can act as a lubricant, and if used in high loadings (greater than 5%), it can inhibit weldability. Black parts on the other hand can be pigmented with carbon, which can also inhibit weldability. In any event, an application evaluation should be undertaken. Parts molded in different pigments may require minor variations in welding parameters.

Resin grade can have a significant influence on weldability because of melt temperature and other property differences. An example is the difference between injection/extrusion grades and cast grades of acrylic. The cast grade has a higher molecular weight and melt temperature, is often brittle, and forms a skin that gives it greater surface hardness, all of which reduce weldability to the injection grade. A general rule of thumb is that both materials to be welded should have similar molecular weight, and melt temperatures within 40°F (22°C) of each other.

COMPOSITES

Filled or reinforced plastics, in which additives, fillers, and reinforcements are combined with the base resin, are widely known as composites. Advanced composites refer to high-performance fibers such as graphite or Kevlar, and high-performance materials formed by means of more complex techniques involving weaving, winding, or otherwise aligning reinforcement into special patterns. The following information deals only with composites.

Fillers/extenders constitute a category of additives (nonmetallic minerals, metallic powders, and other organic materials) added to a resin that alter the physical properties of resins. Fillers enhance the ability of some resins to transmit ultrasonic energy by imparting higher rigidity (stiffness). Common materials such as calcium carbonate, kaolin, talc, alumina trihydrate, organic filler, silica, glass spheres, wollastonite (calcium metasilicate), and micas, can increase the weldability of the resin considerably; however, it is very important to recognize that a direct ratio between the percentage of fillers and the improvement of weldability exists only within a predescribed quantitative range. Up to 20% can actually enhance weldability, due to increased stiffness, giving better transmission of the vibratory energy to the joint.

Resins with a filler content up to 10% can be welded in a normal manner, without special procedures and equipment. However, with many fillers when filler content exceeds 10% the presence of abrasive particles at the resin surface can cause horn wear. In this situation the use of hardened steel or carbide-faced (coated) titanium horns is recommended.

When filler content approaches 35%, there may be insufficient resin at the joint surface to obtain reliable hermetic seals; and when filler content exceeds 40%, tracking, or the accumulation of filler (typically fibers), can become so severe that insufficient base resin is present at the joint interface to form a consistent bond.

It should be noted that particular types of fillers can present special problems. When long fibers of glass are employed, they can collect and cluster at the gate area during molding, being forced through in lumps rather than uniformly dispersed. This agglomeration can lead to an energy director containing a much higher percentage of glass. If this were to occur, no appreciable weld strength could be achieved since the energy director would embed itself in the adjoining surface, not providing the required molten resin to cover the joint area. If this problem occurs, it can be eliminated by utilizing short-fiber glass filler.

Fibrous reinforcements of resins can, like fillers or extenders, be used to enhance or alter physical properties of the base resin. Continuous or chopped fiber strands of aramid, carbon, glass, etc., can in some cases improve the weldability of a resin; however, rules governing the use of fillers should be observed.

BRANSON ULTRASONICS CORPORATION
Eagle Road, Danbury, CT 06813-1961 (203) 796-0400